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Reaching to net zero energy: The recipe to create zero energy homes in warm temperate climates

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Abstract

Building energy policy in many countries is firmly pointed towards a need for net zero energy homes. But given the limited range of operational energy impacts that can be directly influenced by building regulations, and the wide variation in energy use behaviours of building users, what system performance levels will be required to ensure new homes achieve that standard? This paper utilises in-home energy monitoring from a near net zero energy estate to provide the evidence of the system performance needed for all major end-uses, for homes in warm temperate climates to achieve, on average, a net zero operational energy standard. The evidence presented in this paper points to the combination of passive solar design strategies, energy efficient appliances, and active solar systems that will lead to net zero energy performance given contemporary lifestyles and the impact of the digital age.

Selection and peer-review under responsibility of KES International

Keywords: Residential energy consumption; building energy regulation; household energy monitoring; zero energy home

1. Introduction

Building energy regulatory policy in many countries is moving towards levels approximating net zero energy or net zero carbon [1]. In the United Kingdom the target has been set at net zero carbon for new dwellings by 2016 [2]; in Europe the EU Directive on the Energy Performance of Buildings [3] specifies that by the end of 2020 all new buildings shall be 'nearly zero energy buildings' [4]; and other nations such as the USA and Korea have begun exploring a policy path to net zero energy buildings by the 2020s [4].

The concept of combining passive solar design strategies with energy efficient devices and renewable energy technologies is not particularly new. Case studies demonstrating the potential for extremely low energy homes have appeared in many countries and many climates, and recently the International Energy Agency's "Towards Net Zero Energy Solar Buildings" project mapped almost 300 net zero energy and energy-plus buildings worldwide [5].

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Whilst creating bespoke net zero energy homes has been demonstrated through monitored results for individual buildings, missing from the debate has been a discussion about the strategies, technologies and system performance levels that can be applied en-mass via building energy regulations to achieve the net zero energy balance. With building energy regulations likely to be a key policy mechanism to reduce household energy use for new homes, it is important to understand which energy systems can be addressed through regulation, and what strategies will be required given the high energy lifestyles of contemporary households.

This paper explores the available evidence from a near net zero energy residential estate to address the research question: what combination of energy system performance targets will facilitate reaching a net zero operational energy building standard for new homes? By addressing this key gap in the literature, this paper will help policy makers understand the task needed to achieve net zero or near net zero energy housing standards.

2. Literature review

The building energy literature provides plenty of evidence that the reduction of operational energy use through the application of passive solar design, appliance efficiency and local renewable energy supply technologies [1, 6-10]. For example: Kapsalaki and Leal [1] examined so called net zero energy homes in USA, Canada, Germany, Austria and the United Kingdom to document the design strategies, and concluded that reaching a zero or even positive net yearly energy balance was not technically difficult and could be reached by combining standard building design practice with sufficient on-site renewable energy generation systems.

The literature also provides a number of detailed and high level strategies for reducing the energy impact of residential buildings [1, 11-13]. Some approaches such as employed by Boardman [11] focus on the specifics of the local building stock and have limited application to other climates and other building typology. Other literature including Torcellini [12] and Ren et al [13] present higher level strategies which have a more universal application. Common is an initial focus on building design and energy efficiency to reduce demand, followed by the application of renewable energy technologies.

Authors such as Crawford [14] and Hernandez and Kenny [15] suggest that any strategy must also incorporate actions to reduce the building's embodied energy. Whilst this approach has merit, due to the current state of uncertainty associated with the calculation of life-cycle energy impacts within building regulatory instruments [16], for this paper the net zero energy calculation will be limited to operational energy use.

The literature also contains a number of detailed strategies for reaching a net zero energy performance [17-19]. For example: Abakr et al. [19] examined the different strategies needed for temperate and tropical bioclimatic zones; and Newton and Tucker [17] explored the key strategies required to reach a net zero carbon performance in a mild temperate zone. While these strategies provide useful insights into the design and technology pathways to low energy and zero energy homes, they are all based on modeled or estimated energy demand and may not represent the likely demand associated with actual household behaviours. But these strategies are heavily weighted towards engineering solutions and miss the key issue that buildings don't use energy, people do. Behavioural scientists such as Schipper et al [20] and Lutzenhiser [21] point to almost identical buildings in the same climate, with an almost identical fitout, which due to user behaviour result in energy end-use differences of up to 300 per cent. Shove [22] suggested that households are central to the energy equation, as active assemblers of their own routines, creating the structures and conventions of everyday life.

There is a substantial body of empirical evidence that engineering improvements in energy efficiency, including improvements to building thermal comfort, do not deliver expected energy savings [23, 24]. The evidence in the literature points to a thermal comfort related rebound effect that contracts as building thermal efficiency increases and the demand for thermal comfort is satisfied [23]. The lighting energy literature shows a similar rebound effect, where demand for artificial lighting continues to grow as the efficiency and cost effectiveness of delivering light improves [25]. Any proposed strategy for reaching a net zero energy target will need to take into account actual energy use behaviours such as the rebound effect and those associated with contemporary digital age lifestyles.

By their nature building codes can directly influence a limited set of actions, specifically those design and technology elements that are built into or fixed to the structure of the building, rather than the materials and technologies brought to the building by the end user household [16]. This means that building codes are typically limited to influencing the efficiency of providing energy services such as artificial lighting, thermal comfort and hot water, and with net zero energy homes this would extend to the provision of on-site energy generation technologies. Energy use related to other energy services such as entertainment, laundry, cooking, cleaning, and home office needs are not usually directly influenced through building codes and standards but can be significant energy loads that must be included to facilitate a net zero energy balance. Whilst the efficiency of some electrical appliances and equipment is regulated through national or multi-national minimum energy performance standards, the amount of equipment installed, their efficiency and use patterns, are not directly impacted by building regulation.

By examining the major areas of energy use, the technologies that typically provide the energy services, and the behaviour of building users, it is possible to identify strategies for reducing energy use in residential buildings and develop energy system targets that will support a net zero energy balance. This paper extends our knowledge of net zero energy home strategies by utilising actual energy use behaviour from near zero energy homes to determine the building energy regulatory standard that will produce, on average, a net zero energy outcome for new homes.

3. The case study

The Lochiel Park Green Village in South Australia has been chosen as the most appropriate case study due to: (a) the relatively large size of the sample set; (b) the quality and detail of energy end-use data available; (c) the closeness of average building energy performance to a net zero energy target; and (d) the representativeness of the householder characteristics, being similar in a range of demographics to the regional population.

Lochiel Park was created through government policy to become a suburb of over 100 (nearly) net zero energy homes in a near zero-carbon estate [26]. The energy used and generated at each house is being monitored and analysed to extend our understanding of what happens when users bring their energy habits to near zero energy homes. Appliance and equipment audits, and user interviews have been conducted to extend our knowledge of the energy service expectations of contemporary digital-age lifestyles. All homes at Lochiel Park are built to the same high environmental standard, published in the Urban Design Guidelines [27]. The minimum requirements include:

- 7.5 NatHERS Stars thermal comfort (i.e. <58 MJ/m2 per annum to maintain thermal comfort)
- Solar water heating, gas boosted
- 1.0kWp photovoltaic system for each 100m2 of habitable floor area
- High energy star rated (energy efficient) appliances
- Capacity limited to 4kVA (input) for space conditioning systems
- Energy efficient lighting (i.e. compact fluorescent lights CFLs or light emitting diodes LEDs)
- Ceiling fans in all bedrooms and living spaces
- An in-home energy feedback display

The Urban Design Guidelines established a new set of rules, calling for practices outside existing institutional and professional norms, requiring the application of technologies and systems uncommon to the mainstream building industry at the time, and the consideration of new performance indicators bringing new concepts to building design and construction practices [26].

The age profile, household size and type, and other demographics of the residents are reasonably similar to the State profile rendering the estate a useful case study to investigate household energy use. All houses at Lochiel Park are detached or semi-detached two story buildings, ranging from 1 bedroom studio apartments to 4 bedroom family homes, the typical having 3 bedrooms. The average floor area is 203.3 m^2, similar to the 2008/9 South Australian average for new homes being 199.3 m^2 [28]. The local climate is temperate with mild winters and relatively hot summers reaching peaks over 35^{o}C. Cooling is provided by either evaporative coolers, ducted or split system reverse cycle air-conditioners. Heating is provided by either reverse cycle air-conditioners, small gas room heaters, or underfloor heating. All homes include ceiling fans to promote air flow and low energy thermal comfort.

All homes incorporate passive solar design principles to decrease the need for additional heating and cooling. The NatHERS 7.5 Star (<58MJ/m^2 per annum to maintain thermal comfort) requirement for building thermal efficiency represents a significant increase above the local stock average which approximates NatHERS 2.5 Stars (<270MJ/m^2 per annum) [29], and the local building regulatory standard of NatHERS 5 Stars (<125MJ/m^2 per annum) applied at the time these homes were approved for construction. NatHERS thermal simulation ratings are based on annual sum of the heat energy required to be added or removed to maintain thermal comfort due to building design and construction characteristics, local climate data and standardised household user behaviour patterns. Further detail on the NatHERS thermal comfort energy rating scheme is available at [30].

Figure 1 shows a typical Lochiel Park floor plan, having a larger ground floor area with the primary living spaces and the master bedroom, and the additional bedrooms located on the first floor. The living, dining and kitchen zones, being the most frequently used living spaces, are located on the ground floor with North oriented glazing. When combined with external shading devices, a concrete high mass floor, and relatively high levels of insulation, these passive solar spaces are designed to maintain thermally comfortable conditions throughout the year without the need for substantial amounts of additional space heating or cooling.

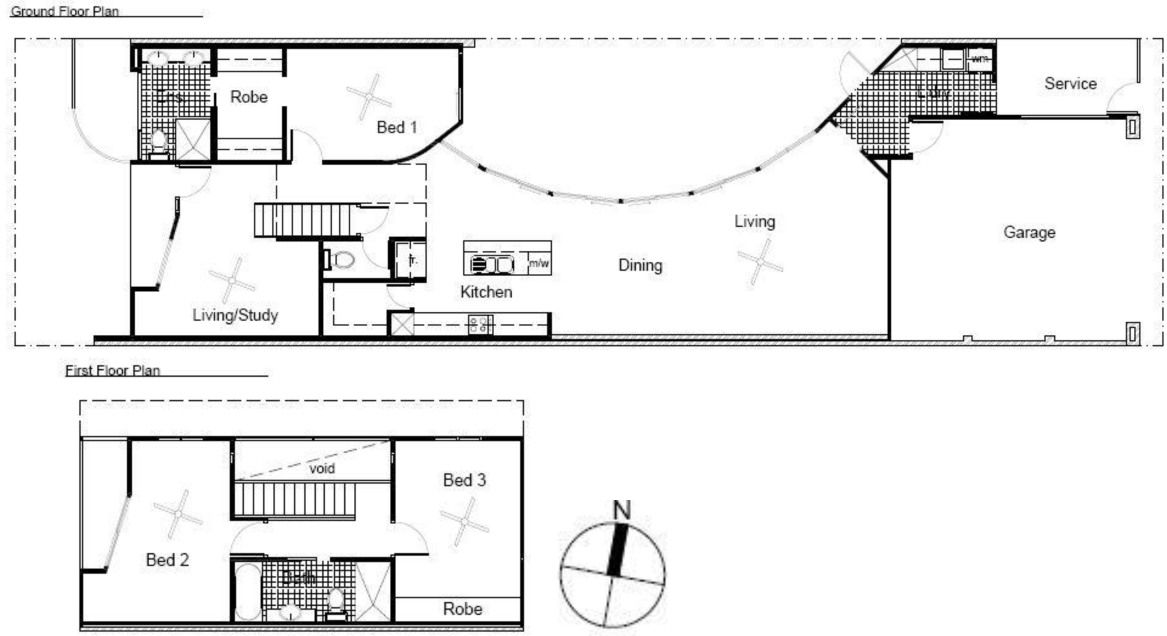

Figure 1: A typical Lochiel Park floor plan

The data presented in this study is based on monthly analysis of one minute interval data collected from the monitoring system and feedback display installed in each Lochiel Park dwelling. Although electricity, gas and water use, and electricity generation information is collected, the focus of this paper is on operational energy use. Ten homes have additional monitoring equipment to collect indoor temperatures and energy use from various appliances (i.e. air conditioners, lights, etc.); these are referred to as *detailed* monitored houses. Further monitoring system information is available in [31]. Water heating energy performance is extracted from a Saman et al. report which draws on monitored data from a similar sample of Lochiel Park case study households [32].

4. Energy end-use at Lochiel Park

The case study shows that energy use in near net zero energy homes presents a different picture to that of more typical homes in the same climate. When compared to the end-use breakdown for Australian average stock figures for a similar period, the relative proportion of energy used for space heating and cooling, and for water heating, for the sample of near net zero energy homes is noticeably lower [33]. General plug loads related to home entertainment, home office, laundry, etc have increased in relative importance. The total amount of energy used in the case study homes is also significantly lower compared with the Australian stock figures, averaging 28.3 GJ per household (2010-13) against the expected Australian average of 47.5 GJ in 2012 [34]. Interesting is the variation in energy use between the households (caused by factors such as: number or occupants, user behaviour, number of electrical appliances/devices, etc.), which is relatively large. After removing floor area as a factor, the variation in energy use ranges from over 50 MJ/m^2 to 250 MJ/m^2 for this sample of homes built to a common building energy standard. Any building standard seeking at achieve an average net zero energy balance will need to take into account the behaviour of prospective households.

5. System performance targets

The net energy balance, as used in this paper, is the total of the energy used for maintaining thermal comfort, lighting, water heating, and general plug loads; less the energy generated from the on-site renewable energy system. Because building energy regulations are typically limited to the control of building design and those technologies installed for providing the energy services of thermal comfort, artificial lighting and water heating, these energy impacts will be treated individually, with all other services combined as 'non-regulatory' energy use. This section draws on the monitored data to establish energy relationships for each of the major energy end uses and for electricity generation from the on-site photovoltaics. By using monitored energy data from near net zero energy homes, behavioural impacts such as thermal comfort rebound are incorporated.

And while individual nation's building energy codes may require only the total net energy balance to be zero, separate energy system targets may provide useful guidance or encourage strategies that focus on the efficient use of energy prior to the netting of that energy use by on-site renewable energy generation.

5.1. Thermal comfort function

Whilst the annual energy used for maintaining thermal comfort varies greatly at each NatHERS star level due to individual household behavioural patterns, technology efficiency and climate variability, patterns can be inferred from examining samples of homes (reducing the impact of behavioural variation), monitored for several years (reducing the impact of climatic variation), using similar technology (reducing the impact of technology efficiency).

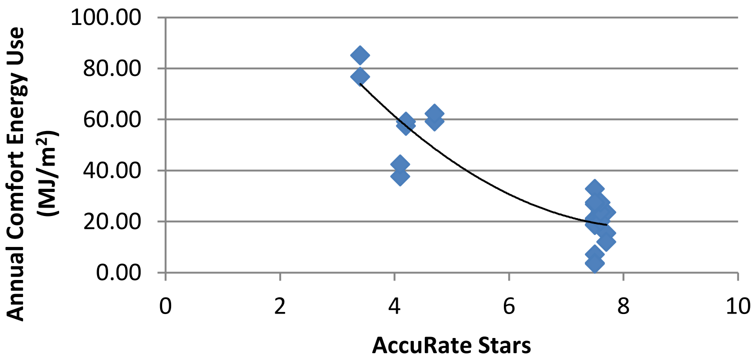

Figure 2: Annual thermal comfort energy use per unit floor area versus NatHERS star rating for detailed monitored homes in Lochiel Park and detailed monitored homes in Mawson Lakes.

Figure 2 presents the annual energy used for thermal comfort per unit floor area against the NatHERS star level for a sample of 6 homes monitored for 3 consecutive years at Lochiel Park and a sample of 4 homes monitored for 2 years at Mawson Lakes [35], all using reverse cycle air conditioners with a similar efficiency (CoP) as the primary supplement for thermal comfort (supplementing passive systems). Although the sample sizes are small, and the monitoring period is relatively short, a reasonably strong relationship (R^2 value = 0.8079) can be seen between annual thermal comfort energy use and the NatHERS star rating assigned.

Annual comfort energy use (MJ) = (2.2*NatHERS Rating^2 – 37.6*NatHERS Rating + 176)*floor area

The NatHERS rating scale relates increased thermal efficiency with increased costs as lowest cost opportunities are taken up, and therefore the energy difference in star levels reduces as the star level increases to the maximum 10 Stars. Given the marginal energy benefit associated with an increase in the thermal efficiency of the building fabric beyond 7.5 Stars, a suitable minimum building code target could be 7.5 NatHERS Stars (i.e. <58 MJ/m^2 per annum).

5.2. Lighting energy function

Annual lighting energy use is a function of the fixed indoor lighting capacity per unit floor area and the behaviour of occupants. And although the relationship is not particularly strong (R^2 value = 0.2116), this monitored sample indicates that as the fixed lighting capacity per unit floor area increases, annual energy use increases.

Annual lighting energy use (MJ) = (67.0*fixed lighting capacity per m^2 + 112.4kWh)*3.6

The current building regulations in Australia sets the maximum fixed lighting energy density at $5W/m^2$ for habitable areas, yet over 30% of homes at Lochiel Park (sample size = 46) achieve a level less than $3W/m^2$ using commonly available technology. Given the increasing availability of energy efficient lighting products, a suitable building code target would be a fixed lighting energy density no greater than $3W/m^2$.

5.3. Water heating function

Although individual household water heating energy use varies according to hot water use behaviour and bespoke thermostat settings, Figure 3 shows that for two distinct types of water heating technology, a clear pattern emerges. From the monitored energy use data, water heating energy use is a function (R^2 value = 0.3542) of the estimated solar contribution using Small-Scale Technology Renewable Energy Certificates (STCs) as the de facto metric. The number of STCs awarded is based on the estimated amount of electricity (MWh) the solar component of the system displaces. Further information about STCs is available from the Australian Government [36].

Figure 3 shows that the solar water heating systems with an instantaneous gas boost achieving a 40 STC rating have an annual energy use, on average, less than half that of the 26 STC rated solar water heaters with storage tanks that are gas boosted to maintain a sufficiently high temperature.

Annual hot water energy use (MJ) = 21551 MJ – 424.7 * STC rating

Given the widespread availability and application of higher efficiency water heaters, a suitable building code target would be to require water heating systems with a rating of no less than 40 STCs.

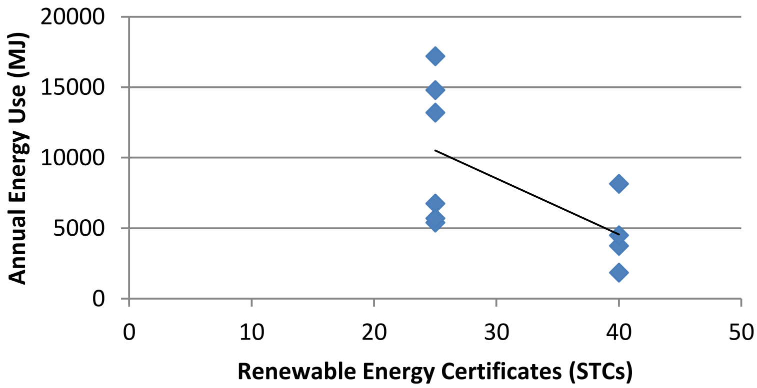

Figure 3: Annual water heating energy use versus Renewable Energy Certificates for selection of monitored homes in Lochiel Park

5.4. Non-regulatory energy function

Non-regulatory energy use varies according to the number and type of appliances brought to the home, their pattern of use, and the profile of the household, with individual households using more than twice that of others for energy services such as entertainment, laundry, and home office. From this sample of monitored homes, average annual energy use for all non-regulatory energy functions is around 13776MJ (Standard Deviation = 4559MJ). Random household reference codes have been used to maintain the confidentiality of the respective households.

5.5. Total energy use

From the detailed monitoring of homes at Lochiel Park we can see in Table 1 that for this sample average total energy use approximates 26.9 GJ per annum, with just over half due to non-regulatory energy services.

Table 1: Actual energy use for a sample of homes at Lochiel Park

Actual energy use (MJ)					
Household	Comfort	Lighting	Non Reg	HW	Total
W	1653	933	9077	6750	18413
CC	3919	1939	11252	5400	22510
J	4239	1743	19689	*10508	36178
Y	3684	481	8513	1850	14528
AA	4910	1572	19788	*10508	36779
S	5953	1631	14032	*10508	32124
Q	6619	776	16100	*4563	28058
Average	*4425*	*1296*	*14064*	*7155*	*26941*

* Average figure for specific technology

When the fixed lighting energy density is limited to no greater than 3W/m^2 and the water heating system is changed to a minimum 40 STC solar product to meet the proposed zero energy standard, after taking into account the behaviour of each household, average total energy use (see Table 2) reduces to around 23.1 GJ per annum. Whilst this appears to be a relatively small improvement in total energy use, it must be noted that these homes were already designed to be near net zero in annual delivered energy.

Table 2: Improved energy use for a sample of homes at Lochiel Park

Improved energy use (MJ)					
Household	Comfort	Lighting	Non Reg	HW	Total
W	1653	859	9077	2931	14521
CC	3919	1925	11252	2345	19441
J	4239	1185	19689	*4563	29676
Y	3684	481	8513	1850	14528
AA	4910	1029	19788	*4563	30291
S	5953	1071	14032	*4563	25619
Q	6619	526	16100	*4563	27808
Average	*4425*	*1011*	*14064*	*3625*	*23126*

* Average figure for specific technology

In particular, Table 2 shows that the new standard has decreased artificial lighting energy use by a small amount and water heating energy use by a significant amount, compared to the initial requirements used to create the estate. The initial standards were more stringent than required in the Building Code of Australia.

5.6. Renewable energy generation function

Across the case study estate (sample size = 43) the average photovoltaic system size is 2.42kWp, producing approximately 12,450 MJ/yr. The efficiency for individual photovoltaic systems to generate electricity is related to a number of factors including the type of panel, elevation (tilt angle), panel orientation, and the incidence of shading from nearby obstructions. Figure 4 shows the range of performances for the sample of systems monitored at Lochiel Park (latitude 34.9^o South) for a 12 month period.

Whilst the average generation performance for the systems is a little over 5MJ per peak watt installed (R^2 = 0.6482), it is noticeable that several systems are significantly underperforming due to system faults, orientation, over-shadowing or other installation problems. The reality of a large scale roll out of rooftop photovoltaics is that orientation, elevation, and the incidence of shading will vary away from optimal performance. For the purpose of building regulations in latitudes near 30^o-35^o South (Sydney, Adelaide, Perth, Canberra), annual energy generation from photovoltaic systems = 5.05MJ per Wpeak rating.

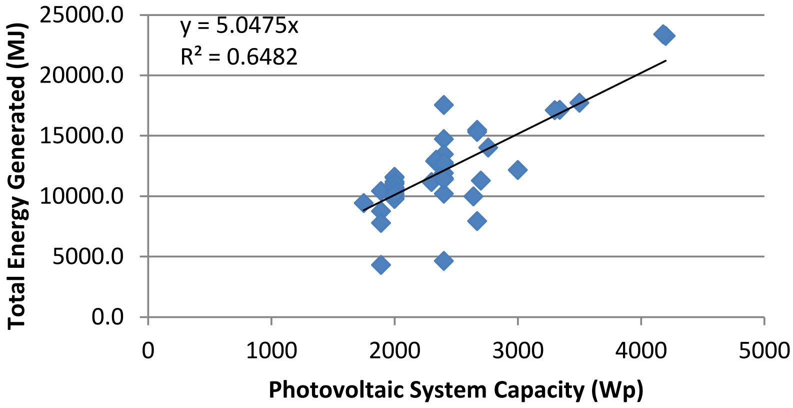

Figure 4: Annual energy generation versus photovoltaic system capacity for homes in Lochiel Park

5.7. Reaching net zero

To reach an average annual net zero energy balance, energy generation will need to equal the amount of energy used, although not necessarily when that energy was used. The case study evidence shows that irrespective of individual household behaviour, household size or the size of the dwelling, a minimum amount of energy is used to provide the average non-regulatory (i.e. entertainment, laundry, home office, etc) energy services expected by contemporary households. Once this 'fixed' amount of energy is provided by the on-site generation system, then the amount demanded varies according to the size of the household, the size of the dwelling and the amount of energy services demanded by the individual household. In simple terms the net zero energy balance can be delivered by a 'fixed' amount of generation capacity and a 'variable' generation capacity linked to an appropriate metric. As building codes and standards are applied before the household takes occupancy, household size is unknown but floor area or the number of bedrooms are known design details which could be used as the regulatory metric.

The evidence available from the Lochiel Park case study suggests that a 'fixed' minimum generation capacity equivalent to a 2.75kWp photovoltaic system would provide sufficient energy to balance the non-regulatory energy services need, with a 'variable' generation capacity of 1.0kWp per each 100m^2 of floor area. This means that larger homes designed to accommodate larger households would be required to generate more energy to maintain the net zero energy balance. Across the population of new homes, the delivered energy balance would be net zero.

By applying the individual energy use functions and including the non-regulatory load for a typically sized 200m^2 new home, meeting a 7.5 NatHERS Star rating, with a 40 STC solar hot water system, and a fixed lighting system of 3 W/m^2; the total annual energy use would average 22,995 MJ, with the photovoltaic system generating on average 23,843 MJ per annum (see Table 3).

Table 3: Annual energy use for a 200m^2 new home calculated from the energy model

Energy Service	Energy Use (MJ)
Thermal Comfort	3550
Lighting	1107
Water Heating	4563
Non-regulatory	13776
Total	**22995**
less generation	
Generation (2.75+2)kWp PV	**23843**

Table 3 shows that for an example 200m^2 new home constructed to the proposed building energy standards, the average annual amount of electricity generated will offset the energy use for all energy services, achieving a net zero delivered energy impact on the local energy grid. This example does not try to balance each fuel type by primary energy factors, but rather nets all fuel types according to the amount of energy used on site for daily operational purposes. Actual energy use in any specific household will vary according to household behaviour, the efficiency of installed technologies and the climate conditions at that time, but across a large sample of new homes, and across a number of years, the average delivered energy balance is expected to be net zero.

6. Discussion and conclusion

The impact of each fuel type is not considered for the purpose of this paper. Primary energy factors could be used for each fuel type to determine the primary energy balance. The energy embodied in the materials and processes that produce and maintain the building is also not considered, although further research may be able to determine the amount of additional generation capacity required for a net zero life-cycle energy balance to be achieved.

This paper is limited to examining the engineering and behavioural aspects of a net zero energy standard for new homes and does not consider the economics of applying the standard. Further research will be necessary to determine whether the proposed standard would satisfy the economic tests applied to building regulatory.

The case study investigates energy use associated with the building typology, lifestyles and household sizes typically found in warm temperate climates. Local building styles, climatic and household lifestyles will impact on the demand for each energy service and the amount of electricity needed to achieve a net zero energy balance.

A larger sample of monitored homes, more representative of recently constructed local building stock, and with a range of household types, sizes and lifestyles more representative of the wider population would provide greater certainty in calculating average energy service demand and in demonstrating a net zero energy balance.

From the available evidence drawn from this sample of near net zero energy homes, this paper has identified individual energy service performance targets that when combined with non-regulatory energy loads and on-site electricity generation could achieve a net zero annual operational energy balance. These individual targets for thermal comfort, lighting, water heating and electricity generation are suitable for building energy standards.

For the Building Code of Australia: increasing the thermal comfort standard from 6 NatHERS Stars to 7.5 NatHERS Stars; increasing the fixed lighting energy standard from a maximum 5 W/m^2 to 3 W/m^2; increasing the water heater standard from a minimum of 26 STCs to 40 STCs; and adding a minimum electricity generation (photovoltaic system) requirement equivalent to 2.75kWp plus 1.0kWp per each 100m^2 of habitable floor area, will enable new homes to achieve, on average, a annual net zero delivered energy balance.

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Response to reviewer's comments

Reviewer comment	*Response*
Reviewer A	
For those not familiar with the NatHERS rating system, it would be helpful to have a little more explanation of how this represents thermal comfort, since that is such a key aspect of the study.	A sentence has been added to the NatHERS discussion in Section 3 to explain how the NatHERS rating system measures thermal comfort.
How are the specific energy services improved?	Section 5.5 has been rewritten to clarify the specific changes made to each energy service.
The idea that there is a 'fixed' amount of energy is used to provide basic services is not well explained. To add that demand varies depending on "the amount of energy services demanded by the individual household" is not particularly illuminating. Doesn't this simply mean that people want different levels of comfort?	Section 5.7 has been rewritten to explain the link between average non-regulatory energy use and the fixed amount of on-site generation, showing balance between the 'fixed' energy service demand and the fixed on-site generation.
Reviewer B	
Section 3, pp2. - Whilst the Lochiel Park Green Village case study is obviously relevant, it is still important for authors to discourse on the choice of their methodology, i.e. why exactly this case study, how representative is it, approach to case study selection and its consequent relevance to research findings. A short explanatory paragraph to this extent should suffice.	Several statements have been added to Section 3 to describe why Lochiel Park is a relevant case study for the research.
Section 3, pp3. - Whilst not strictly necessary, it would be nice to see couple of images/drawings/photographs of the site layout, typology and/or typical cross sections of buildings, including their sustainable design features, services integration and renewables provision.	A floor plan of a typical Lochiel Park home has been included, with additional text describing the arrangement of rooms, and passive solar design elements.
Section 4, pp3. - A short paragraph describing location and key characteristics of climate/micro climate would be appreciated by the reader not familiar with this part of Australia.	A description of the climate has been added to Section 3.
Section 4, pp3. - How valid is comparison of data collected for Lochiel Park 2010-13 when compared to Mawson Lakes 2002-3? That is 10 years difference! Explain, please.	A note has been added explaining the similarity in climate for the two periods.
Section 5.1, pp5. - Brief explanation of NatHERS stars rating and requirements is needed for readers not familiar with this system.	A sentence has been added to the NatHERS discussion in Section 3 to explain how the NatHERS rating system measures thermal comfort.
Section 5.4, pp6. - Provide legend for W CC J Y AA S Q	A sentence has been added to Section 5.4 to explain the household reference code.
Chair	
Your paper is one page too long. I suggest you reduce the number of references, this is a conference paper and not a journal paper.	The number of references has been reduced and the paper limited to 10 pages.